THREE-DIMENSIONAL TEXTILE COMPOSITE STRUCTURE AND MANUFACTURE AND USE THEREOF

BACKGROUND

1. Field of the Invention

The present invention relates to three-dimensional textile composite structures with energy-absorbing capacities under multiple impacts, and to the manufacture and use thereof.

2. Background of the Invention

Three-dimensional textile composite structures have been widely used for energy absorbing purposes. For example, U.S. Patent 6,536,052, issued to Xiaoming Tao et al. on March 25, 2003 and entitled "Safety Helmets with Cellular Textile Composite Structure as Energy Absorber," discloses a porous textile composite structure with high energy-absorbing capacities. Preferred embodiments of '052 suggest spraying and then curing thermoset resins onto knitted fabrics for achieving the desired textile composite structures.

However, disadvantages exist with such knitted textile composite structure according to the preferred embodiments as disclosed in '052.

Firstly, it is observed that under multiple impacts, the knitted textile composite structure according to the preferred embodiments as disclosed in '052 may exhibit unsatisfactory energy-absorbing performance. In particular, the three-dimensional knitted textile composite structure may collapse at the first impact and therefore lose a substantial part of its energy-absorbing capacities.

Furthermore, it is also observed the process of spraying and curing thermoset resin onto the fabrics is time consuming. It may take several days for the resin to cure at ambient temperatures.

OBJECT OF THE INVENTION

Therefore, it is an object of the present invention to provide a textile composite structure with energy-absorbing capacities under multiple impacts, preferably such a structure being made by a faster and more convenient process as compared to '052, or at least provide the public with a useful choice.

SUMMARY OF THE INVENTION

According to an aspect of present invention, a three-dimensional textile composite structure with energy-absorbing capacities under multiple impacts includes a base, and at least one progressively collapsible projection extending from the base for absorbing energies under the multiple impacts. The projection includes a non-woven textile material supported in a thermoplastic matrix material such that the projection is capable of retaining energy-absorption capacity at least after the first impact of the multiple impacts.

According to a second aspect of the present invention, a process for manufacturing a textile composite structure capable of retaining energy-absorption capacity at least after the first impact of multiple impacts includes the steps of:

providing a layer of non-woven textile material;

laminating a layer of thermoplastic matrix material with the non-woven textile layer, the thermoplastic matrix material melting at a lower temperature than the non-woven textile;

heating the laminate to a processing temperature higher than the melting temperature of the thermoplastic matrix material but lower than the melting temperature of the non-woven textile material;

applying pressure to the heated laminate for impregnating the non-woven textile material with the melted thermoplastic matrix material; and

molding the non-woven textile material impregnated with the thermoplastic matrix material to a desired shape with a base and a plurality of progressively collapsible projections extending from the base.

According to a third aspect of the present invention, an energy-absorbing door includes:

inner and outer panels joined together in spaced apart relation; and

an energy absorbing structure provided on the inner panel including at least an energy-absorbing sheet of textile composite having a base and a plurality of projections extending from the base,

wherein each projection includes a non-woven textile material supported in a thermoplastic matrix material such that the projection is capable of retaining energy-absorption capacity at least after an initial impact.

According to a fourth aspect of the present invention, a safety headgear includes:

an outer shell; and

an energy-absorbing liner within said outer shell including at least an energy-absorbing sheet of textile composite having a base and a plurality of projections extending from the base,

wherein each projection includes a non-woven textile material supported in a thermoplastic matrix material such that the projection is capable of retaining energy-absorption capacity at least after an initial impact.

According to a fifth aspect of the present invention, a body protective gear includes:

an outer shell; and

an energy-absorbing liner within the outer shell including at least an energy-absorbing sheet of textile composite having a base and a plurality of projections extending from the base,

wherein each projection includes a non-woven textile material supported in a thermoplastic matrix material such that the projection is capable of retaining energy-absorption capacity at least after an initial impact.

According to a sixth aspect of the present invention, a protective package includes:

an outer shell; and

an energy-absorbing liner within the outer shell including at least an energy-absorbing sheet of textile composite having a base and a plurality of projections extending from the base,

wherein each projection includes a non-woven textile material supported in a thermoplastic matrix material such that the projection is capable of retaining energy-absorption capacity at least after an initial impact.

According to another aspect of the present invention, a seat cushion includes:

an outer shell; and

an energy-absorbing liner within the outer shell including at least an energy-absorbing sheet of textile composite having a base and a plurality of projections extending from the base,

wherein each projection includes a non-woven textile material supported in a thermoplastic matrix material such that the projection is capable of retaining energy-absorption capacity at least after an initial impact.

Other aspects and advantages of the invention will become apparent from the following detailed description, taken in conjunction with the accompanying

drawings, which description illustrates by way of example the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1A is a perspective diagram of a sheet-like textile composite structure according to an exemplary embodiment of the present invention;

Figure 1B is top plan view of the textile composite structure of Figure 1A;

Figure 1C is a cross sectional view of the textile composite structure of Figure 1A;

Figure 1D is a cross sectional view of the textile composite structure of Figure 1A, illustrating deformation of the textile composite structure under an impact;

Figure 2 is a diagram illustrating a process of making the textile composite structure of Figure 1 according to an exemplary embodiment of the present invention;

Figure 3A is a cross-sectional view illustrating a vehicle door in which the textile composite structure of Figure 1 can be used;

Figure 3B is a perspective view of an energy absorbing structure, which is part of the vehicle door of Figure 3A; and

Figure 4 is a cross-sectional view illustrating a helmet in which the textile composite structure of Figure 1 can be used.

DETAILED DESCRIPTION

Figure 1 illustrates an exemplary three-dimensional sheet-like textile composite structure 100 with energy-absorbing capacities under multiple impacts. The textile composite structure 100 has a generally planar base 103 and a plurality of projections 105 extending from the base 103. In the exemplary embodiment, each projection 105 has a grid-domed shape with a conical sidewall 107 and a generally flat top 109. Furthermore, each projection 105 defines a space (not shown) where the sidewall 107 and/or the top 109 may collapse under impacts. Figures 1B and 1C are respective top plan view and cross sectional view of the textile composite structure of Figure 1A.

The textile composite structure 100, at least the projections 105, includes a textile and a matrix material. More specifically, in the exemplary embodiment, the textile structure 100 is made from non-woven fabric materials impregnated with thermoplastic matrix materials.

Materials for producing the non-woven fabric may vary. Examples of the individual yarns in the non-woven fabrics may include strands of fiberglass, carbon, ceramics, and aromatic fibers. A variety of yarns can be used including flat continuous filament yarns, textured or non-textured filament yarns and staple yarns. A mixture of these materials may be used in a single yarn if desired. Preferably, fibers with good mechanical properties for energy absorption and processing are used such as high-density polyethylene, polyester, nylon, and so on. The yarn can be straight or textured including crimped or deformed yarns. Textured yarns may be preferred for the large deformation needed through formation and for better matrix penetration.

Methods for producing the non-woven fabric may also vary. Firstly the orientation of the fiber web prepared for production of the non-woven fabric

can be in parallel, cross-layered, unidirectional or random. Furthermore, various bonding methods such as chemical bonding, thermal bonding, or mechanical bonding can be used to integrate the fibers in the non-woven fabric. The exemplary embodiment uses at least a mechanical bonding method such as needle-punching to create the non-woven fabric of the exemplary embodiment.

Preferably, the non-woven fabric thus produced in the exemplary embodiment is made from staple fibers with a random orientation and a low level of anisotropy in mechanical properties. It is also preferred that the non-woven fabric is resilient and has a bulk form so that the fabric is deformable to form the complex shape and contain sufficient fiber volume fraction in the fabricated composite.

On the other hand, examples of the thermoplastic matrix materials include low density polyethylene, polypropylene, polyester, polyamide, polystymene, polyetheretherketone, polyphenlenesulfide, and so on. The thermoplastic matrix material in the exemplary embodiment may be one of the listed materials or a combination of several materials. In either case, in the exemplary embodiment, the thermoplastic matrix material has a lower melting temperature than the non-woven textile material.

The exemplary sheet-like textile composite structure 100 with projections made from non-woven fabric impregnated with thermoplastic matrix materials as described above exhibits high energy-absorbing capacities at least after the first impact of the multiple impacts. As illustrated in Figure 1D, it is observed that once a repeated impact force hits the tops 109 of the projections 105, rings 111 are progressively formed along the side walls 107 when the projections 105 are deformed under the impacts. Therefore, the tops 109 remain intact under the multiple impacts, and the textile composite

structure 100 retains high energy-absorbing capacities at least after the first impact of the multiple impacts.

Furthermore, such a textile composite structure 100 can be produced through a relatively fast and clean process as discussed in details below.

Figure 2 illustrate an exemplary process of producing a textile composite structure with the capacity of retaining energy-absorption capacity at least after the first impact of the multiple impacts.

Firstly, a laminate 201 of a layer of non-woven fabric and a layer of thermoplastic matrix material is provided. The non-woven layer and the thermoplastic matrix layer are made from the materials and methods according to the above illustrative descriptions accompanying Figures 1A-1C. Furthermore, in the exemplary embodiment, the non-woven fabric has a melting temperature at least approximately 30 degrees Celsius higher than the melting temperature of the thermoplastic matrix material.

The laminate 201 is then heated by a heater 203 in a closed mold cavity (not shown) to a processing temperature higher than the melting temperature of the thermoplastic matrix material but lower than the melting temperature of the non-woven fabric. Preferably, the processing temperature is at least approximately 10 degrees Celsius higher than the melting temperature of the thermoplastic matrix material and at least approximately 10 degrees Celsius lower than the melting temperature of the non-woven fabric. Pressure is also applied to the laminate 201 to force the melted thermoplastic matrix materials to impregnate the fibers of the non-woven fabric in a relatively short period.

The processing temperature, pressure applied and the processing time in the step above are well controlled in the exemplary embodiment to avoid polymer degradation. During processing, both the polymeric non-woven fabric and

thermoplastic matrix are exposed to an elevated temperature. The processing temperature is controlled such that the fabric and the matrix are not exposed to an extremely high processing temperature so as to avoid unnecessary thermal degradation, which may lead to reduction of the molecular weight of the polymers and thus deteriorate its mechanical behaviors. Furthermore, the processing temperature is controlled to avoid non-woven fabric yellowing, which may happen when the non-woven fabric is processed at very high temperature and/or long exposure time. The applied pressure is also monitored and may be varied at different stages of process to release the air inside the compression mold so as to avoid forming voids therein and to reduce the oxidation.

After that, as the laminate 201 is fed by a pair of drive rollers 205 through a pair of heated rollers 207, the laminated 201 is heated to a second processing temperature above the glass transition temperature of the non-woven fabric but below its melting temperature. Thereby, the laminate is thermally softened and partially deformed with the grid-dome-shaped projections 105 temporarily extending from the generally planar bases 103. Subsequently, the partially deformed laminate is fed to a heated mold 209 with grid-dome-shaped projections thereon for permanent molding. After the molding and de-molding, a three-dimensional sheet-like textile structure 100 according to an exemplary embodiment of the present invention is produced, with a generally planar base and a plurality of projections extending from the base.

In the exemplary process described thereabove, the impregnation of the matrix material with the non-woven fabric is achieved within a relatively short period as compared to conventional processes since the heat and press are applied within the closed mold cavity. Furthermore, such a process is proved to be a relatively clean process in that the impregnation of the matrix material with the non-woven fabric is achieved within a closed cavity.

The exemplary textile structure 100 described above may have different applications. For example, in Figure 3A, a cross-sectional view of a typical vehicle door 200 is shown and includes an outer panel 301 and an inner panel 303, which are spaced apart to define a vehicle door structure carrying a window regulator mechanism, door latch, and other components of a vehicle door. The inner and outer panels define a window opening 305.

A door trim panel 307 is formed of a suitable material such as pressed hardboard or plastic and is covered with a suitable decorative material such as vinyl, leather, cloth, carpeting or the like. The door trim panel 307 is attached to the door inner panel 303. An arm rest structure 309 is also mounted on the door inner panel 303.

An energy absorbing structure 311 is also interposed between the door trim panel 308 and the door inner panel 303 in the region above the arm rest 309 and below the window opening 305.

Figure 3B shows a perspective view of the energy absorbing structure 311. Energy absorbing structure 311 may include a pair of three-dimensional textile panels 313, 315 with an interface sheet 317 interposed therebetween. Each textile panel 313, 315 is made from non-woven fabric materials impregnated with thermoplastic matrix materials according to the exemplary embodiments of the present invention as described above and has a generally planar base 319 with a plurality of projections 317 extending therefrom.

The vehicle door 300 with such energy absorbing structure 311 may exhibit high energy absorbing capabilities under multiple impacts.

Figure 4 illustrates a head gear or a helmet 400, for example a bicycle helmet or a safety helmet, having a relatively hard outer shell 401 with an inner liner 403 made of the exemplary textile composite structure embodiment of the

present invention, i.e., a three-dimensional textile structure being made from non-woven fabric materials impregnated with thermoplastic matrix materials and having a generally planar base with a plurality of projections extending therefrom. It is noted that the inner liner has an arcuate shape for fitting the outer shell 401.

It is understood that the exemplary textile composite structure 100 may also have other applications such as body protective gear, protective packaging, mattresses, seat cushions, etc. All of these may generally have an outer shell, soft, semi-rigid or rigid, and an energy-absorbing liner within the outer shell including at least an energy-absorbing sheet of textile composite according to the exemplary embodiment of the present invention, i.e., a three-dimensional textile composite structure being made from non-woven fabric materials impregnated with thermoplastic matrix materials and having a generally planar base with a plurality of projections extending therefrom.